PROGRESS REPORT: THERMALLY INSULATED TEST ROAD; STATE ROAD 26 — PHASE II: PERFORMANCE STUDIES

MAY 1970 — NUMBER 10

BY

J. D. TOENNIESSEN

JHRP

JOINT HIGHWAY RESEARCH PROJECT
PURDUE UNIVERSITY AND
INDIANA STATE HIGHWAY COMMISSION

Progress Report

THERMALLY INSULATED TEST ROAD; STATE ROAD 26
PHASE II: PERFORMANCE STUDIES

TO: J. F. McLaughlin, Director
Joint Highway Research Project

May 27, 1970

File: 6-10-7

FROM: H. L. Michael, Associate Director
Joint Highway Research Project

Project: C-36-16G

A progress report "Thermally Insulated Test Road; State Road 26, Phase II: Performance Studies" by Julius D. Toenniessen, Graduate Assistant in Research on our staff, is presented to the Board. The research has been under the joint direction of Prof. C. W. Lovell, Jr. and Mr. H. R. J. Walsh.

The thermal instrumentation and styrofoam insulation have been installed on State Road 26 west of Rossville, Indiana. The collection and analysis of the temperature data have been initiated and some preliminary graphs have been plotted. The input variables for the 2-D heat flow computer model also have been tabulated.

This report is in fulfillment of a plan of study approved by the Board on September 18, 1969. Its submission coincides with the graduation of Mr. Toenniessen and his departure from Purdue University. Data collection and analysis will continue as previously planned.

Respectfully submitted,

Harold L. Michael

Harold L. Michael
Associate Director

HLM'rg

cc: F. L. Ashbaucher
W. L. Dolch
W. H. Goetz
W. L. Grecco
M. J. Gutzwiller
G. K. Hallock
M. E. Harr
R. H. Harrell
J. A. Havers
V. E. Harvey
F. B. Mendenhall
R. D. Miles
C. F. Scholer
M. B. Scott
W. T. Spencer
H. R. J. Walsh
K. B. Woods
E. J. Yoder

Progress Report

THERMALLY INSULATED TEST ROAD; STATE ROAD 26
PHASE II: PERFORMANCE STUDIES

by

Julius D. Toenniessen
Graduate Assistant in Research

Joint Highway Research Project

File: 6-10-7
Project: C-36-16G

Purdue University
Lafayette, Indiana
May 27, 1970

ACKNOWLEDGEMENTS

The writer wishes to express his gratitude to Dr. C. W. Lovell, Jr., Associate Professor in Civil Engineering, Purdue University, for his assistance and guidance during the course of this study and the preparation of this report.

Financial assistance which made this study possible was provided by the Joint Highway Research Project between the Indiana State Highway Commission and Purdue University, J. F. McLaughlin, Director.

The writer also wishes to express sincere thanks to Mr. H. R. J. Walsh, Director of the Research and Training Center, Indiana State Highway Commission, West Lafayette, Indiana for his advice in many areas, and supervision of all phases of the project carried out by the Training Center. The employees of the Training Center who worked on the project are too numerous to mention but those who deserve special recognition are: Mr. Steven Obermier for calibration of the thermistors; Mr. B. Wayne Brown for thermistor installation; and Mr. David Bowman for installation of thermistors, terminal boxes, water level wells, and weather station and data compilation. I also want to thank Mr. Walsh for the pictures used throughout this report.

Mr. Maurice Bowers, Graduate Assistant at Purdue University deserves special thanks for his work in altering the pattern of temperature sensors to fit the 2-D heat flow model, and for his advice throughout the study.

The employees of Fauber Construction Co., Inc. and the Indiana State Highway Commission who worked on the construction and installation should also be cited for their cooperation and tolerance of some of the inconveniences caused them.

TABLE OF CONTENTS

	Page
List of Figures	v
List of Tables	vii
Abstract	viii
Introduction	1
Planning and Design	1
Construction	2
Data Collection	21
Data Analysis	28
Computer Program	28
Summary	45
Bibliography	45

LIST OF FIGURES

Page

1. Instrumentation of Section "B"; Cross-Section at Station 101 + 00 3
2. Instrumentation of Section "C"; Cross-Section at Station 103 + 00 4
3. Instrumentation of Section "A"; Cross-Section at Station 105 + 00 5
4. Calibration curve of resistance vs. temperature 6
5. Excavation of an access trench 11
6. Drill rig in operation 12
7. Placing a thermistor in the trench wall 13
8. Vibration of the backfill in the trenches 14
9. Placing the Styrofoam boards 16
10. Spreading subbase on the insulation 17
11. Buckling of the Styrofoam 18
12. Placement of a thermistor in the pavement 20
13. Permanent installation of the terminal boxes 22
14. Arrangement of cables in the terminal box 23
15. Thermograph chart 24
16. Sample data sheet of resistances 25
17. Original type of data sheet of temperatures 26
18. New temperature data sheet 27
19. Change with time in the thermal regime on the of Section "A". 29

LIST OF FIGURES (CONT'D)

Page

20. Thermal regime under Section "A" for time = constant 30

21. Difference in thermal regime under the three sections 31

22. Comparison of temperatures below the two insulated sections . 32

23. Change in temperature of the deepest thermistors with time . . 33

24. Profile of Section "B" showing cells and thermistors 35

25. Profile of Section "C" showing cells and thermistors 36

26. Profile of Section "A" showing cells and thermistors 37

27. Types of cells 38

LIST OF TABLES

Page

1. Locations of thermistors in all sections 7
2. Types and dimensions of cells 39
3. Mean Air temperatures 41
4. Ice formation relations in exponential form 42
5. Properties of the cells 43

ABSTRACT

Some of the preparations necessary before the thermistors could be installed are discussed. The many phases of the construction operation including thermistor placement, laying of the Styrofoam, etc., are described and illustrated. The collection, reduction and analysis of the data are discussed and characterized by typical graphical representations. The various inputs necessary for the computer analysis, based upon a 2-D heat flow model, are presented. It is recommended that the study continue as originally planned.

INTRODUCTION

The use of a thermal barrier beneath a highway, in order to minimize frost damage, received impetus with the availability of foamed plastics which are excellent insulators. A number of highway departments have located thermally insulated test roads within their states [1][1], and Indiana is now gaining first hand experience on State Road 26. This is necessary since soils, loads, environment and service requirements vary considerably in different areas.

This pasticular location was chosen because: (1) it is close to Lafayette, which facilitates data collection; (2) the combination of soils, water table and temperature produce a probable frost problem; and (3) the timing of the construction was favorable.

This report summarizes progress on the Insulated Test Road Project during the writer's affiliation with the activity. Much of the work summarized herein, particularly planning, design and construction, was undertaken by others, and the writer has attempted to place the credit where it is due.

PLANNING AND DESIGN

In September, 1967 the JHRP Board approved a plan to locate, design and construct an insulated test road for Indiana. In July, 1968 Stulgis [3] reported such a plan, utilizing a one-dimensional heat flow model for

1. Numbers in brackets refer to listings in the Bibliography, page 45.

design guidance. Late in 1968, Ho [1] developed a two-dimensional heat flow model, and it was deemed desirable to alter the pattern proposed by Stulgis for the temperature sensors.

In the meantime, however, altering the pattern had become physically difficult. The Research and Training Center had decided to use thermistors as the temperature sensors, and to wire and pot (or seal) these in the laboratory into a complete assembly, including the terminal box, ready for burial. This permitted better handling, sealing, and calibration of these delicate sensors, and reduced delays to the road contractor during the installation. As the pattern had to be adapted to the physical constraints of the existing assembly, there was a loss in the order of the alpha-numeric coding. Figures 1 through 3 show the positions of the temperature sensors, and Table 1 lists the exact locations relative to the ground surface.

Under the direction of Mr. Walsh, various potting compounds for the thermistors were tested. Each encapsulated sensor was calibrated by emersing the thermistor in water of a known temperature and recording the resistance across it on an ohmmeter. This was done for various water temperatures between 21°F and 72°F. A sample curve is shown as Figure 4. Curves for all 102 temperature sensors in operation are on file at the Research and Training Center.

CONSTRUCTION

Installation of the thermistors began in early July 1969. Three trenches approximately two feet wide and four feet deep were dug from the centerline to the north ditch; one each at Stations 101 + 00 (Section "B"),

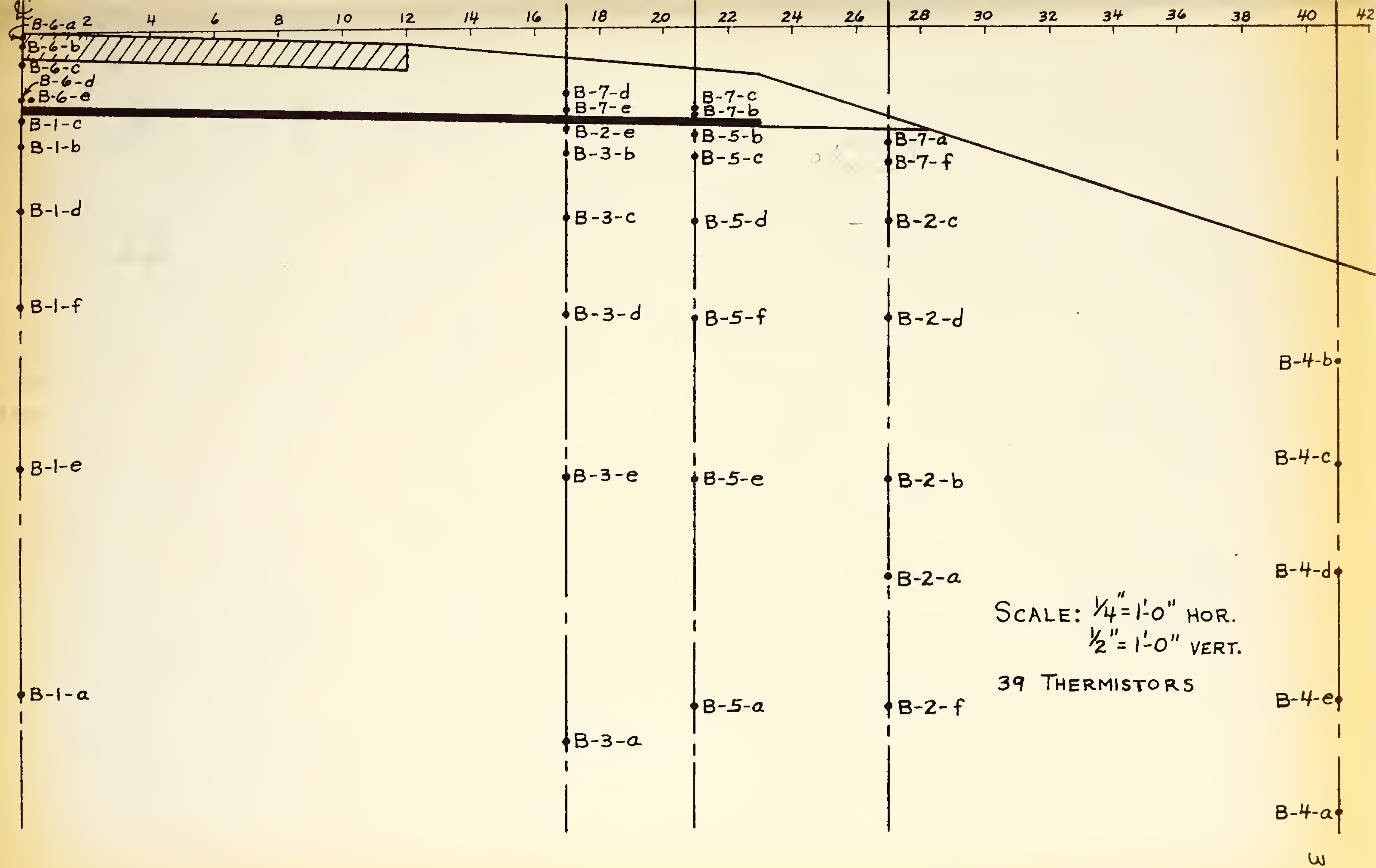


FIGURE 1. INSTRUMENTATION OF SECTION "B" STATION 101+00

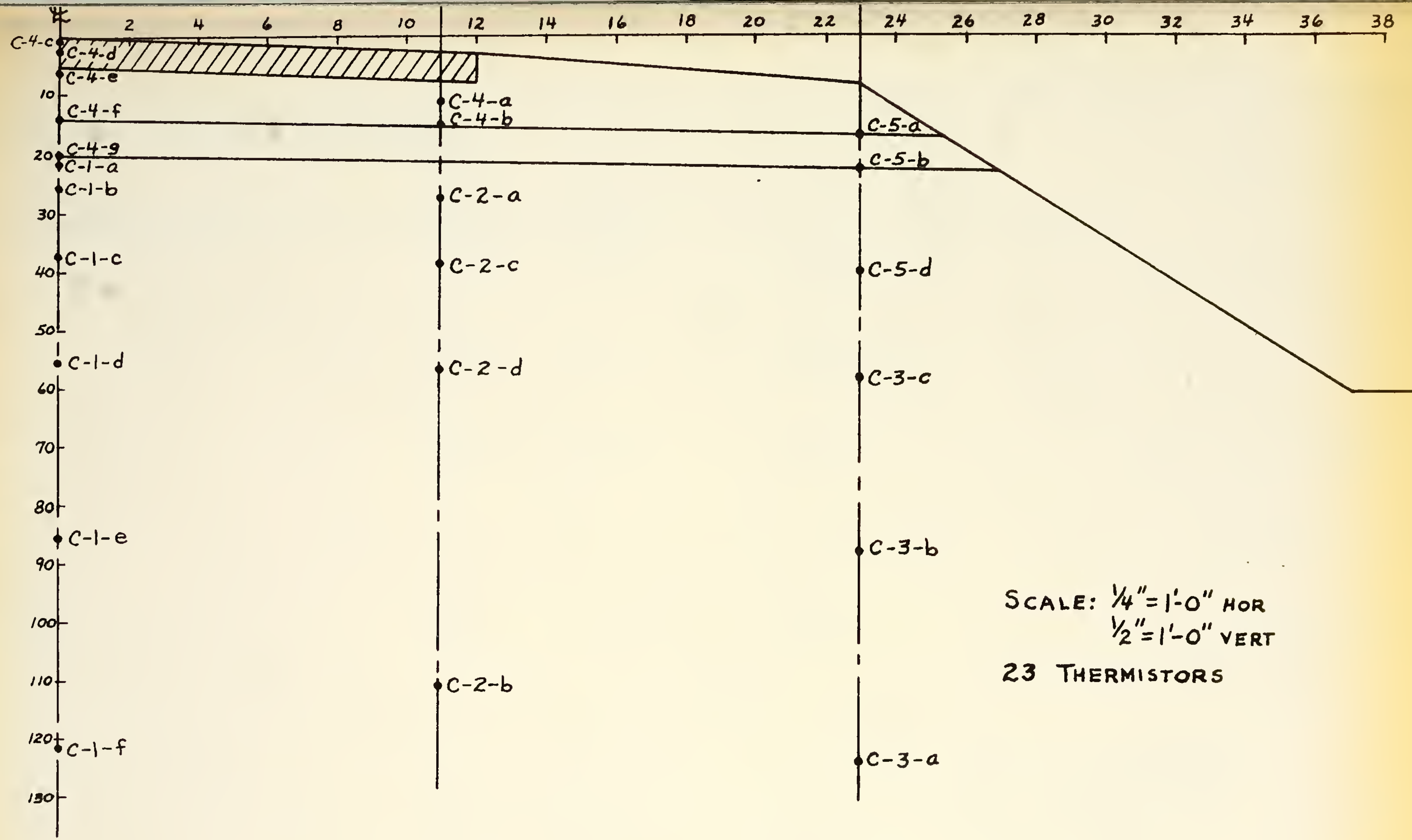


FIGURE 2. INSTRUMENTATION OF SECTION "C" STATION 103+00

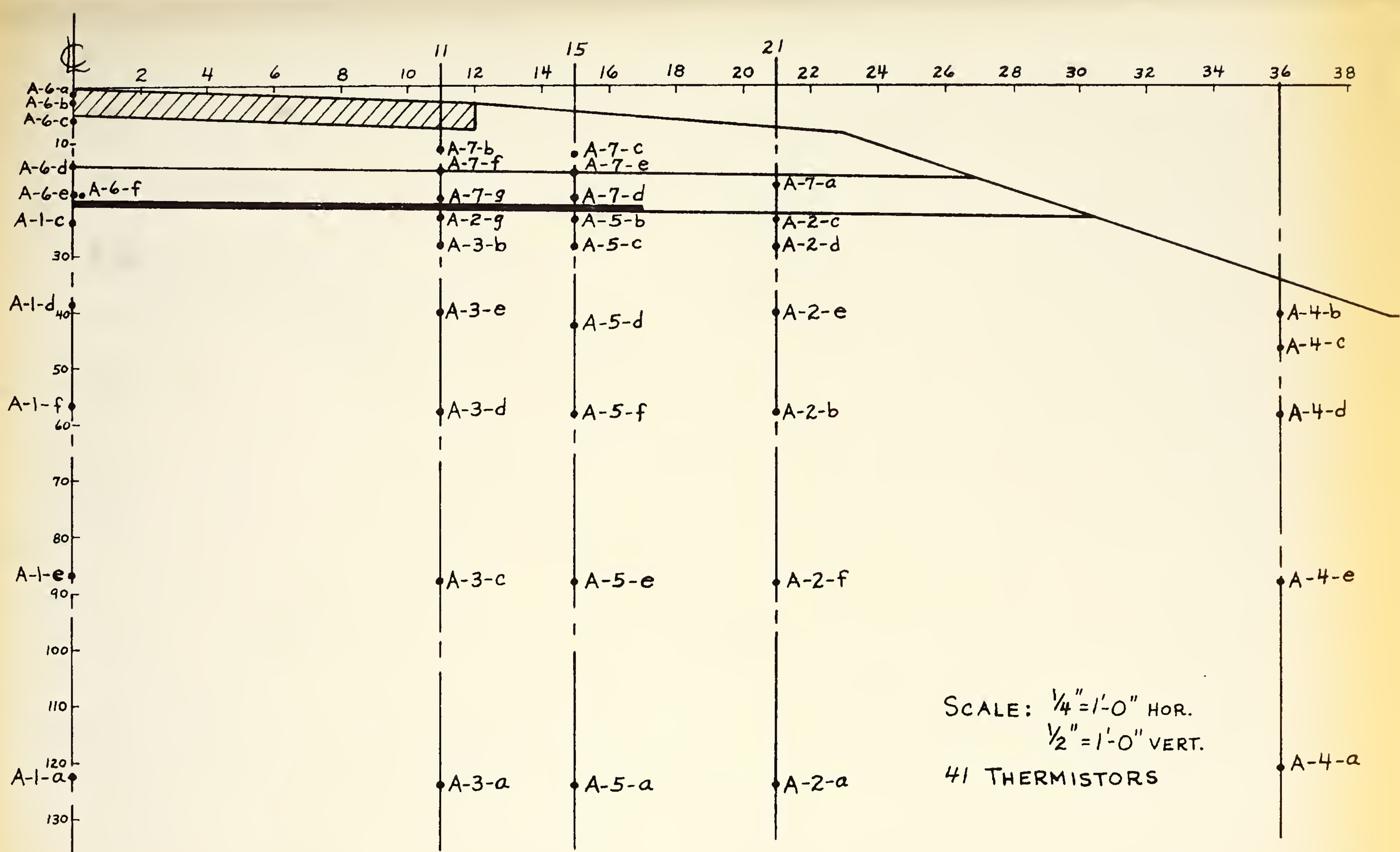


Figure 3. Instrumentation of Section "A" Station 105+00

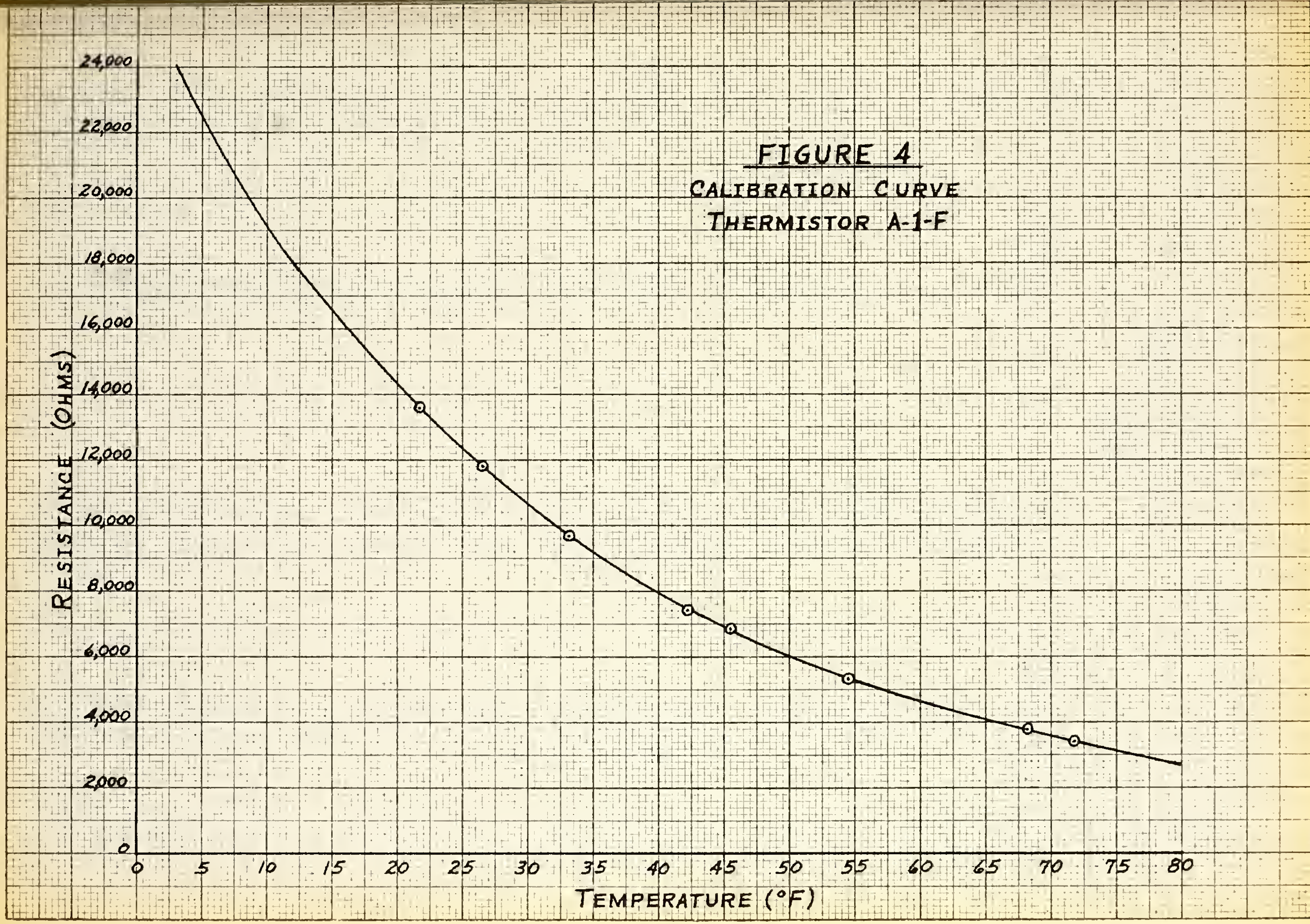


FIGURE 4
CALIBRATION CURVE
THERMISTOR A-1-F
RESISTANCE (OHMS)
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
TEMPERATURE (°F)

TABLE 1

THERMISTOR LOCATIONS

SECTION A

Notation	Distance From Centerline (Ft)	Elevation (Ft)	Depth From Surface (in)
A-6-a	0	530.93	1
-b	0	530.80	2.5
-c	0	530.51	6
-d	0	529.84	14
-e	0	529.43	19
-f	0	529.43	19
A-1-c	0	529.00	24
-d	0	527.76	39
-f	0	526.26	57
-e	0	523.76	87
-a	0	520.76	123
A-7-b	11	530.08	8.5
-f	11	529.73	12.5
-g	11	529.31	17.5
A-2-g	11	529.06	20.5
A-3-b	11	528.64	25.5
-e	11	527.64	37.5
-d	11	526.14	55.5
-c	11	523.64	85.5
-a	11	520.64	121.5
A-7-c	15	530.00	7.5
-e	15	529.69	11
-d	15	529.27	16
A-5-b	15	529.02	19
-c	15	528.60	24
-d	15	527.43	38
-f	15	526.10	54
-e	15	523.60	84
-a	15	520.60	120
A-7-a	21	529.55	10
A-2-c	21	529.05	16
-d	21	528.60	21
-e	21	527.60	33
-b	21	526.10	51
-f	21	523.60	81
-a	21	520.60	117
A-4-b	36	527.60	6
-c	36	527.10	12
-d	36	526.10	24
-e	36	523.60	54
-a	36	520.85	87

TABLE 1 (CONT'D)

THERMISTOR LOCATIONS

SECTION B

Notation	Distance From Centerline (Ft)	Elevation (Ft)	Depth From Surface (in)
B-6-a	0	527.55	1
-b	0	527.42	2.5
-c	0	527.13	6
-d	0	526.55	13
-e	0	526.55	13
B-1-c	0	526.26	16.5
-b	0	525.84	21.5
-d	0	524.84	33.5
-f	0	523.34	51.5
-e	0	520.84	81.5
-a	0	517.34	123.5
B-7-d	17	526.58	7
-e	17	526.36	10
B-2-e	17	526.07	13
B-3-b	17	525.66	18
-c	17	524.66	30
-d	17	523.16	48
-e	17	520.66	78
-a	17	516.61	127
B-7-c	21	526.32	8
-b	21	526.31	8.5
B-5-b	21	526.02	12
-c	21	525.61	16.5
-d	21	524.61	28.5
-f	21	523.11	46.5
-e	21	520.61	76.5
-a	21	517.11	118.5
B-7-a	27	525.86	4.5
-f	27	525.52	8.5
B-2-c	27	524.61	19.5
-d	27	523.11	37.5
-b	27	520.61	67.5
-a	27	519.11	85.5
-f	27	517.11	109.5
B-4-b	41	522.36	18.5
-c	41	520.61	39.5
-d	41	519.11	57.5
-e	41	517.11	81.5
-a	41	515.37	102.5

TABLE 1 (CONT'D)

THERMISTOR LOCATIONS

SECTION C

Notation	Distance From Centerline (Ft)	Elevation (Ft)	Depth From Surface (in)
C-4-c	0	529.24	1
-d	0	529.11	2.5
-e	0	528.82	6
-f	0	528.15	14
-g	0	527.65	20
C-1-a	0	527.59	21
-b	0	527.15	26
-c	0	526.15	38
-d	0	524.65	56
-e	0	522.15	86
-f	0	519.15	122
C-4-a	11	528.32	9
-b	11	528.04	12.5
C-2-a	11	527.00	25
-c	11	526.04	36.5
-d	11	524.54	54.5
-b	11	520.04	108.5
C-5-a	23	527.92	8
-b	23	527.42	14
-c	23	526.92	20
-d	23	525.92	32
C-3-c	23	524.42	50
-b	23	521.92	80
-a	23	518.92	116

103 + 00 (Section "C"), and 105 + 00 (Section "A"). See Figure 5. Holes were augered in the bottom of the trenches at specified locations and to the required depth for the deepest sensor. Figure 6 shows the drilling rig in operation. Bag samples were taken at various elevations for index and other testing. Vertical control was maintained with an engineers level.

After the deepest thermistor was placed, sand was "rained" into the hole to fill to the level of the next thermistor. Backfilling with sand rather than the original material was a compromise, i.e., the artifacts produced by the sand were judged to be less serious than those produced by inadequate filling and compaction of the original material.

Sensors at trench level were pushed into the trench wall. If this was too difficult, the tip of a stake was used to create a hole for the thermistor. See Figure 7. The cables were run up the trench wall and held in place by means of wire clips pushed into the wall. Those to be placed near the subgrade elevation were "stored" at a lower level, along with the cable, to be permanently located later. This was necessary because the subgrade still needed fine grading. The cables to the terminal box were led along the bottom of the trench to the side and the excess was buried with the terminal box in a convenient temporary location. To provide some protection, the box and cables were covered with plastic sheets before the trenches were backfilled.

Trench backfilling was accomplished by somewhat difffferent methods at each location. At Section "C", Station 103 + 00, a layer of sand was placed in the trench by hand and compacted with the vibrator shown in Figure 8. The objective was to minimize the possibilities of damage to

Figure 5. Excavation of an Access Trench

FIGURE 6. DRILL RIG IN OPERATION

FIGURE 7 PLACING A THERMISTOR IN THE TRENCH

Figure 8. Vibration of the Fill in the Trench

the thermistors. Backfilling was then completed by a front-end loader. The trench at Section "A" was filled completely by hand and vibrated in layers. It was watered twice in the process. Final compaction was by rolling with a scraper. In the case of Section "B", a first layer was placed by hand, and the remainder was filled and compacted by a scraper.

It should be noted that the soil profile has been interrupted by sand filling of the drilled holes and by the various trench backfilling procedures.

After the contractor had completed the subgrade, the stored thermistors were permanently located. The terminal boxes were also raised to about one inch below the surface.

The insulation boards were two feet by eight feet by the required thickness; those placed at Section "A" were one inch thick, at Section "B", one and one-half inch thick. The Dow Chemical Company product, Styrofoam Hi was used. The boards were placed outward from the centerline with the plain butt joints occurring at the mid-length of the adjacent string of boards. This is shown in Figure 9. The total width of insulation is 46 feet at Section "B" and 34 feet at Section "A". The length is 200 feet, 100 feet on each side of the station where the sensors are located. The boards were nailed to the subgrade with four-inch wooden spikes to keep them butted together firmly. Considerable care was exercised to avoid driving a spike into a thermistor or cable.

After the Styrofoam was installed, the subbase or base course material was placed. It was dumped from the trucks and spread by a front-end loader. Spreading progressed from Section "C" to Section "A". As indicated by Figure 10, the spreader worked on the gravel, never directly on the boards. At one point a board buckled, as shown in Figure 11. It was flattened, weighted by shovels of the base material, and covered normally.

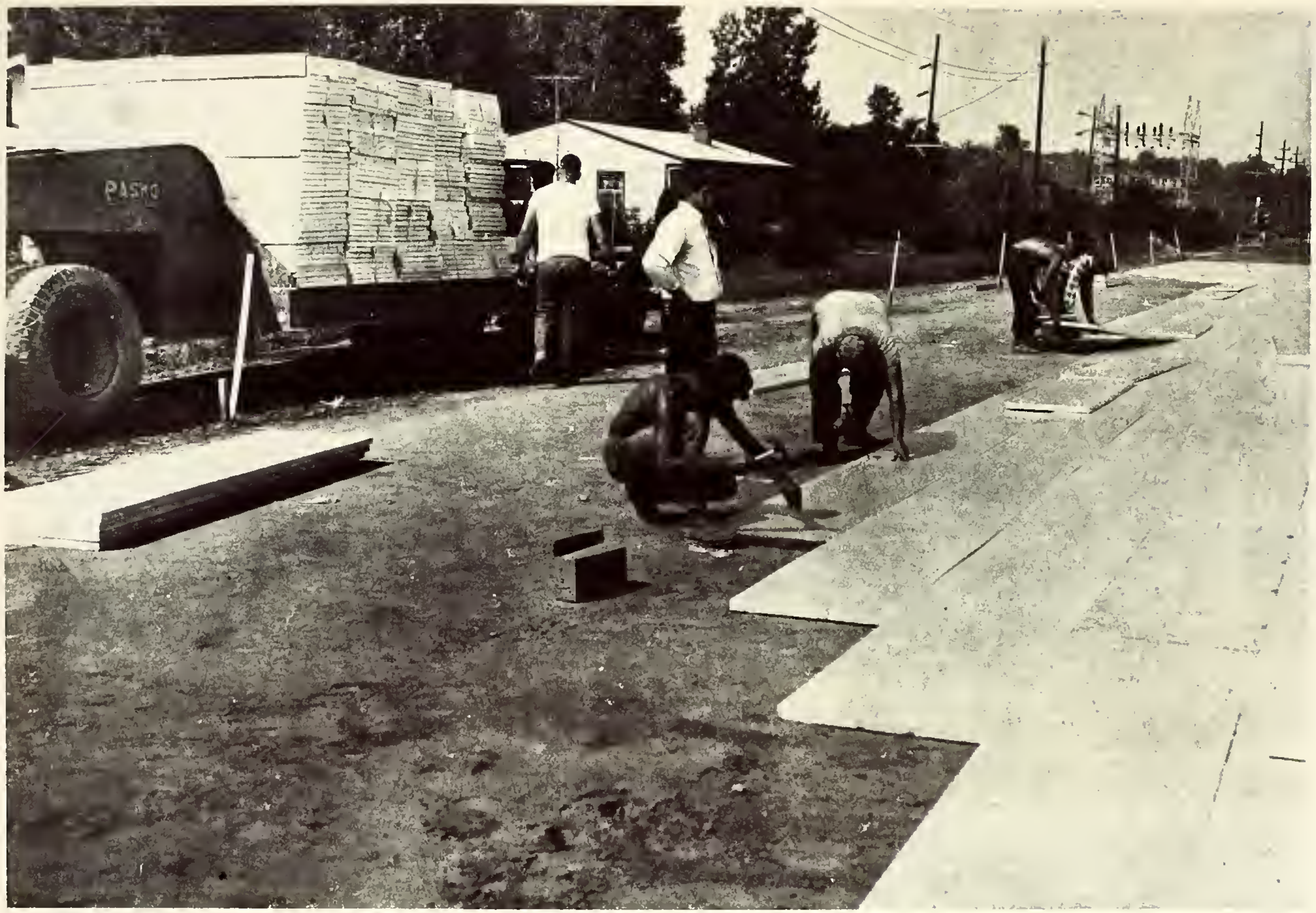


FIGURE 9. PLACING THE STYROFOAM BOARDS

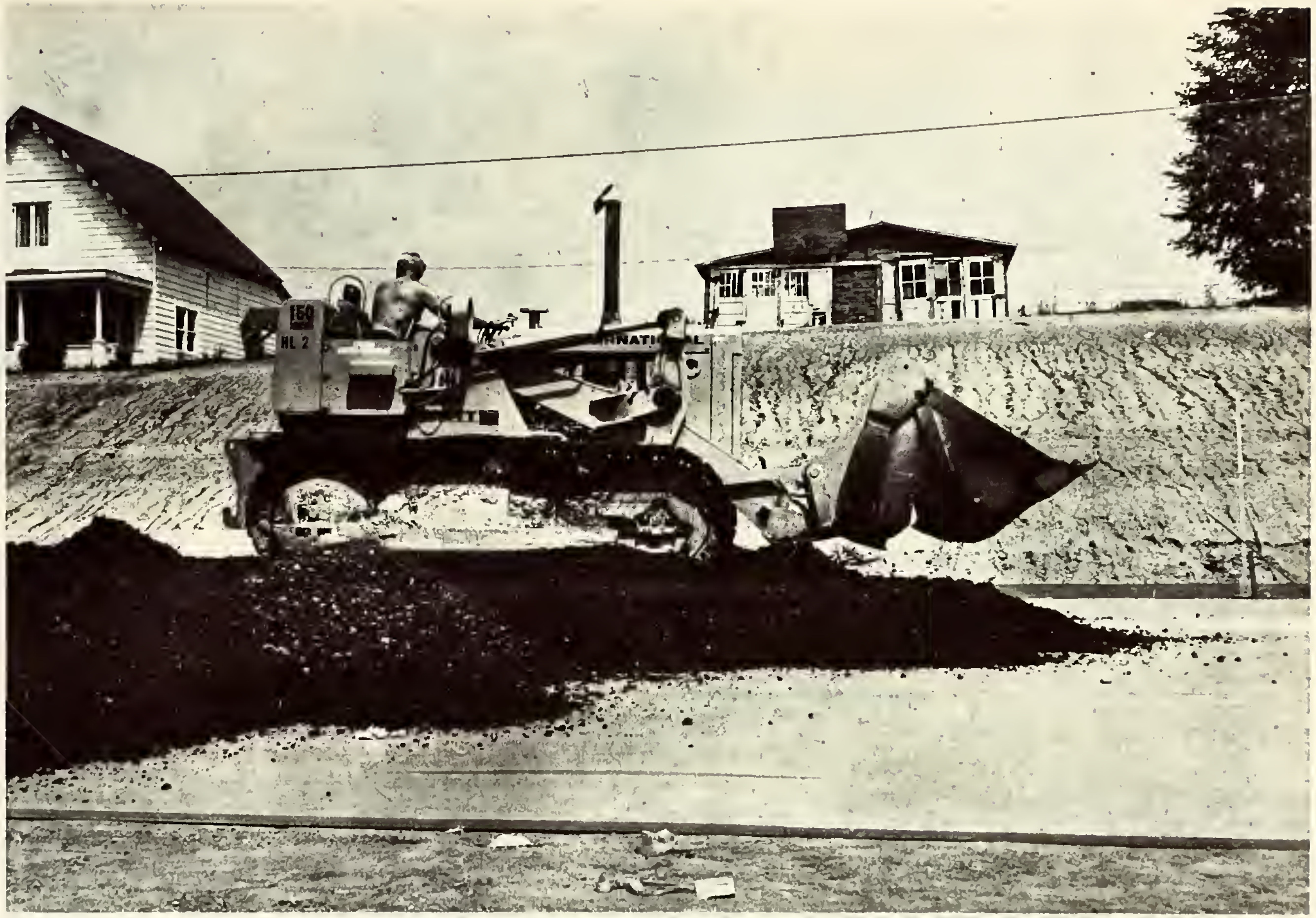


Figure 10. Spreading Subbase on the Insulation

FIGURE 11. BUCKLING OF THE STYROFOAM

The spreading at Section "B" was accomplished more rapidly by using two front-end loaders and a scraper, and by working from both ends toward the middle. This technique produced no noticeable buckling or other undesirable effects. After placement and compaction of the first granular lift, further placement and compaction proceeded in a normal manner. A small portion of the insulation was uncovered in Section "A" to inspect for evidence of damage caused by construction. None was found at this location.

The next step was placement of the thermistors in the subbase and base materials. This was done by trenching through the granular materials, laying the cables along the top of the Styrofoam, and pushing the thermistors into the trench wall. The trench was then backfilled and recompacted. The upper-most sensors were placed in the bituminous material by digging out and patching. See Figure 12. All such thermistors lay below the final surface layer.

After all paving and side slope grading was completed, the terminal boxes and remaining thermistors were given final placement. A trench was dug from the temporary terminal box locations to the extreme thermistor locations outside the paved area. Holes were augered at the appropriate locations in the trenches. The thermistors were lowered individually to the predetermined elevations and backfilled by raining sand into the bore holes. A careful check was kept on the elevations with a surveyors level.

A 1 1/4-inch diameter perforated pipe was installed in the ditch section at Station 104 + 00, for water level observations. A weather station was installed just west of the Rossville town limits, south of State Road 26 on state right-of-way. It consists of a standard shelter, 7-day thermograph, and a non-recording rain gage.

FIGURE 12. PLACEMENT OF A THERMISTOR IN THE PAVEMENT

Finally, concrete boxes were formed below the ground surface at the three sections to provide permanent locations for the terminal boxes. Figure 13 shows the concrete base for the box and Figure 14 shows the arrangement of the terminals in the box before extra cable was added. Each box has a metal lid secured by 2 padlocks. The extra cable was added to the terminals to make it possible to take readings in the comfort of a car... an important convenience in sub-freezing temperatures.

The first readings of the thermistors were taken on November 12, 1969, with a regular schedule of reading beginning on November 20, 1969.

DATA COLLECTION

Responsibility for the collection of data lies with the Research and Training Center. It has been agreed that reading once a day on working days will be sufficient until enough data and predictions are generated to indicate that a different time interval is necessary. Once a week the chart from the thermograph (See Figure 15) is replaced. High and low temperatures for each day are extracted from such charts and the daily means are calculated.

Figure 16 is a sample data sheet of resistances and Figure 17 shows the form originally used to record the temperatures. A revised, more convenient form is shown as Figure 18.

The Research and Training Center is planning to compile two separate reports on the project. One report will be a compilation of the data. The second report will cover the instrumentation procedure and development. These reports will be on file at the Center for reference by anyone interested in this type of project.

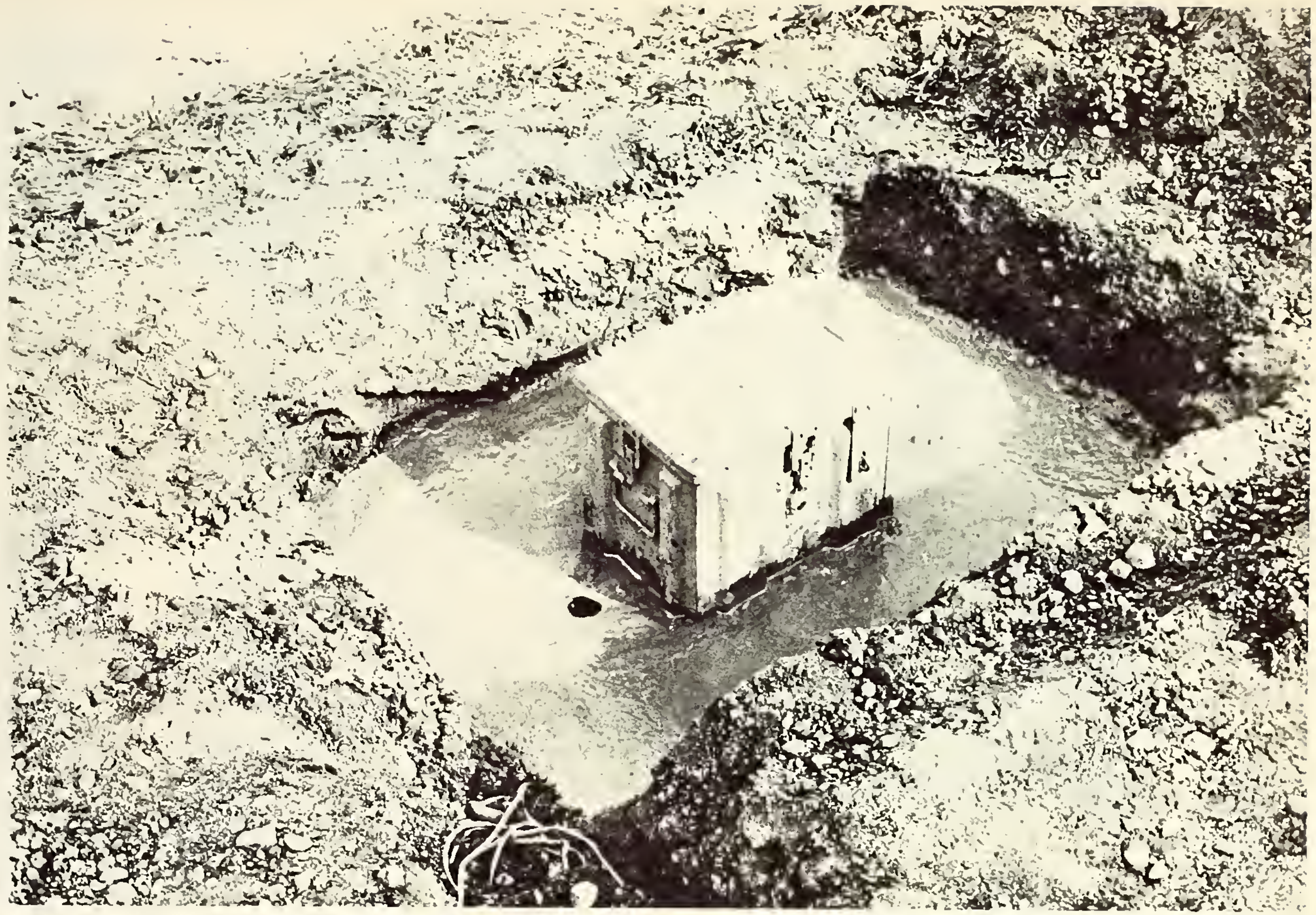


FIGURE 13. PERMANENT INSTALLATION OF A TERMINAL BOX

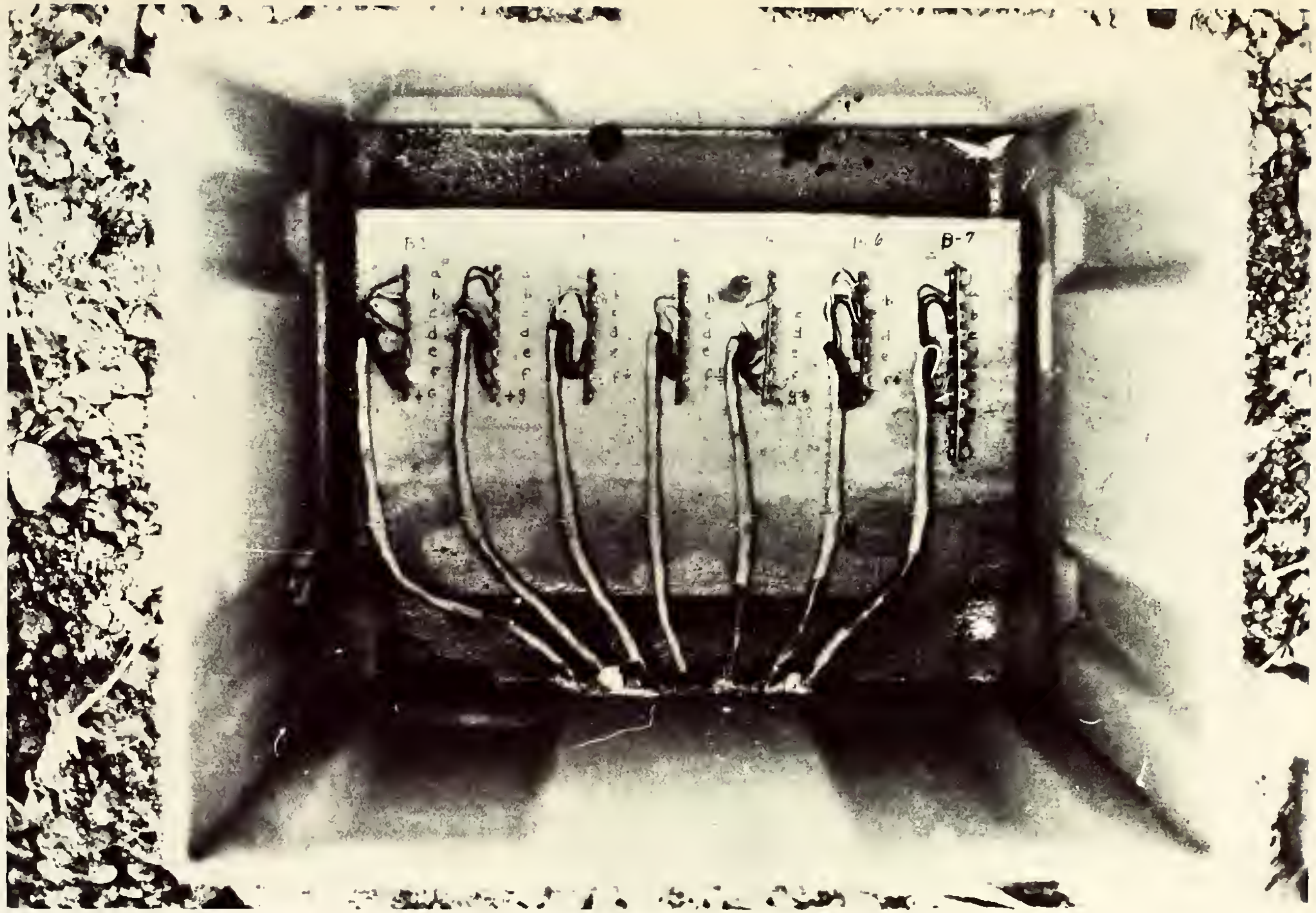


FIGURE 14. ARRANGEMENT OF CABLES IN THE TERMINAL BOX

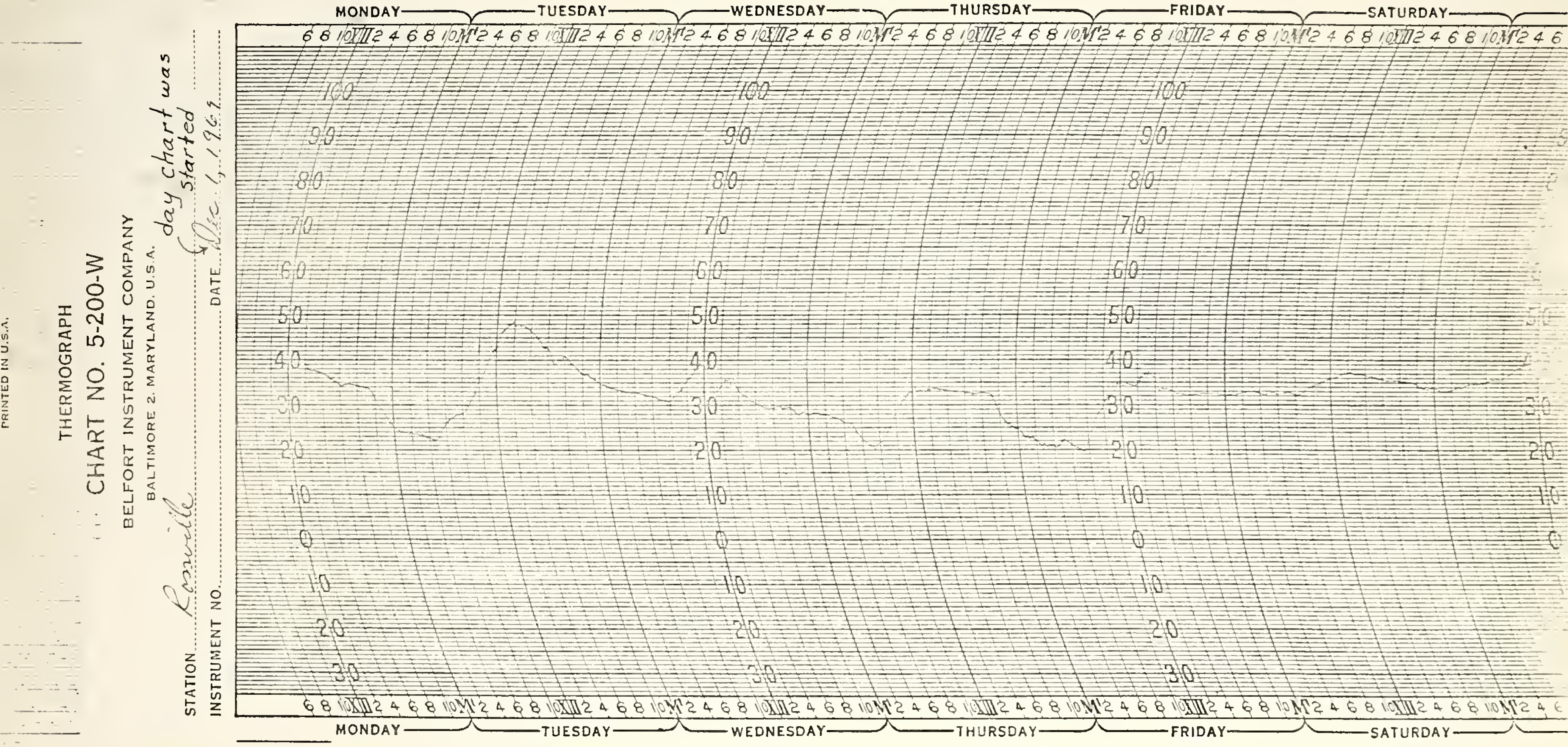

PRINTED IN U.S.A.
THERMOGRAPH
CHART NO. 5-200-W
BELFORT INSTRUMENT COMPANY
BALTIMORE 2, MARYLAND, U.S.A.
STATION
INSTRUMENT NO.
DATE
day chart was started
MONDAY
TUESDAY
WEDNESDAY
THURSDAY
FRIDAY
SATURDAY
100
90
80
70
60
50
40
30
20
10
0
10
20
30

FIGURE 15

TEMPERATURE GAUGE READING

Box A

FIGURE 16. RESISTANCE READINGS

	1	2	3	4	5	6	7
	Resistance in Ohms	Resistance in Ohms	Resistance in Ohms	Resistance in Ohms	Resistance in Ohms	Resistance in Ohms	Resistance in Ohms
a	4760	5250	5150	6000	5050	7070	9100
b	∞	6840	6230	9300	7000	7840	8950
c	6070	8920	5230	9000	6820	8440	9030
d	5670	8700	5630	8100	6330	8710	9130
e	4990	7900	6300	6840	5400	8610	9130
f	5370	5880			5980	8610	8940
g		6480					8840

Date: 12/1/69 Time: 2:15 PM

Air Temperature at Reading: 39°

Temperature for the day: High 39 Low 25

Precipitation:

Depth to Water from Top of Wellpipe No Water in well

Amount of Precipitation:

Remarks

TEMPERATURE GAUGE READING

Box A

FIGURE 17. TEMPERATURE READINGS

	1	2	3	4	5	6	7
	Temperature in °F	Temperature in °F	Temperature in °F	Temperature in °F	Temperature in °F	Temperature in °F	Temperature in °F
a	59.5	54.9	58.9	50.5	56.6	31.9	33.6
b	—	45.4	47	35.2	44	31.4	32.9
c	50.2	36.2	55.2	35.4	45	32.9	32.9
d	51.9	37.4	31.9	39.2	47.3	34.5	35
e	57.5	41	47.1	45.1	53.9	36.1	33.6
f	54.2	51.3			49.8	36	34.3
g		46.7					35.9

Date: 12/2/69 Time: 9:40

Air Temperature at Reading 32°F

Temperature for the day: High 48.7 Low 22

Precipitation:

Amount of Precipitation:

Depth to Watertable from Top of Wellpipe

Remarks

TEMPERATURE DATA
STYROFOAM INSULATION PROJECT
INDIANA STATE HIGHWAY COMMISSION RESEARCH AND TRAINING CENTER

STATION 105+00 LOCATION A DATE 12/2/69 TIME 9:40

AIR TEMPERATURE AT READING: 32° TEMPERATURE FOR DAY: HIGH 48.7 LOW 22

Distance Left of Centerline	36 Ft.		21 Ft.		15 Ft.		11 Ft.		Centerline	
	ELEV *	TEMP. F	ELEV.	TEMP. F	ELEV.	TEMP. F	ELEV.	TEMP. F	ELEV.	TEMP. F
SURFACE	528.85		530.38		530.63		530.78		531.01	
5" BITUMINOUS PAVEMENT									530.93	31.9
									530.80	31.4
9" AGGREGATE BASE					530.00	32.9	530.08	32.9	530.51	32.9
6" SUBBASE			529.55	33.6	529.69	33.6	529.73	34.3	529.84	34.5
					529.27	35	529.31	35.9	529.43	36.1
									529.43	36.0
					//////	//////	1" STYROFOAM		//////	//////
	527.60	34.2	529.05	36.2	529.02	44	529.06	46.7	529.18	N. R.
	527.10	35.4	528.60	37.4	528.60	45	528.64	47	528.76	50.2
	526.10	39.2	527.60	41	527.43	47.3	527.64	47.1	527.76	51.9
	523.60	45.1	526.10	45.4	526.10	49.8	526.14	52.5	526.26	54.2
	520.85	50.5	523.60	51.3	523.60	53.9	523.64	55.2	523.76	57.5
			520.60	54.9	520.60	56.6	520.64	58.9	520.76	59.5

*ELEVATIONS REFERENCED TO MEAN SEA LEVEL DATUM.

FIGURE 18. NEW TEMPERATURE DATA FORM

DATA ANALYSIS

The dependent variable is of course temperature (θ). Principle independent variables are those of position ((x) transverse, (Y) longitudinal and (z) depth) and time (t).

A number of options are being exercised in the graphic representation of the data. One possibility is to interpret temperature contours on the profiles, particularly the 32°F line, holding (y) and (t) constant, while varying (x) and (z). Other possibilities are: (1) holding (x) and (y) constant and varying (t) and (z); and (2) holding (x) and (t) constant while varying (y) and (z). The latter is something of a problem because the cross-sections are different at each of the three stations of measure.

In addition, the two insulated sections can be compared by plotting temperature with depth beneath the Styrofoam. Or a plot of temperature with time for a particular thermistor or several thermistors, coupled with a plot of air temperatures vs. time, shows time lag effects. Example of selected plots are contained in Figures 19 through 23.

From the limited data collected to date the insulation appears to be functioning well. Temperatures are substantially higher below the Styrofoam than above it, while the control section exhibits a rather uniform temperature gradient throughout. The data also show that temperatures are reduced above the Styrofoam relative to the uninsulated section. Apparently the insulation is effectively blocking upward heat flow from the warmer soil at depth.

COMPUTER PROGRAM

The comparison of the actual temperature readings with those predicted by the 2-D heat flow model is an important aspect of this project.

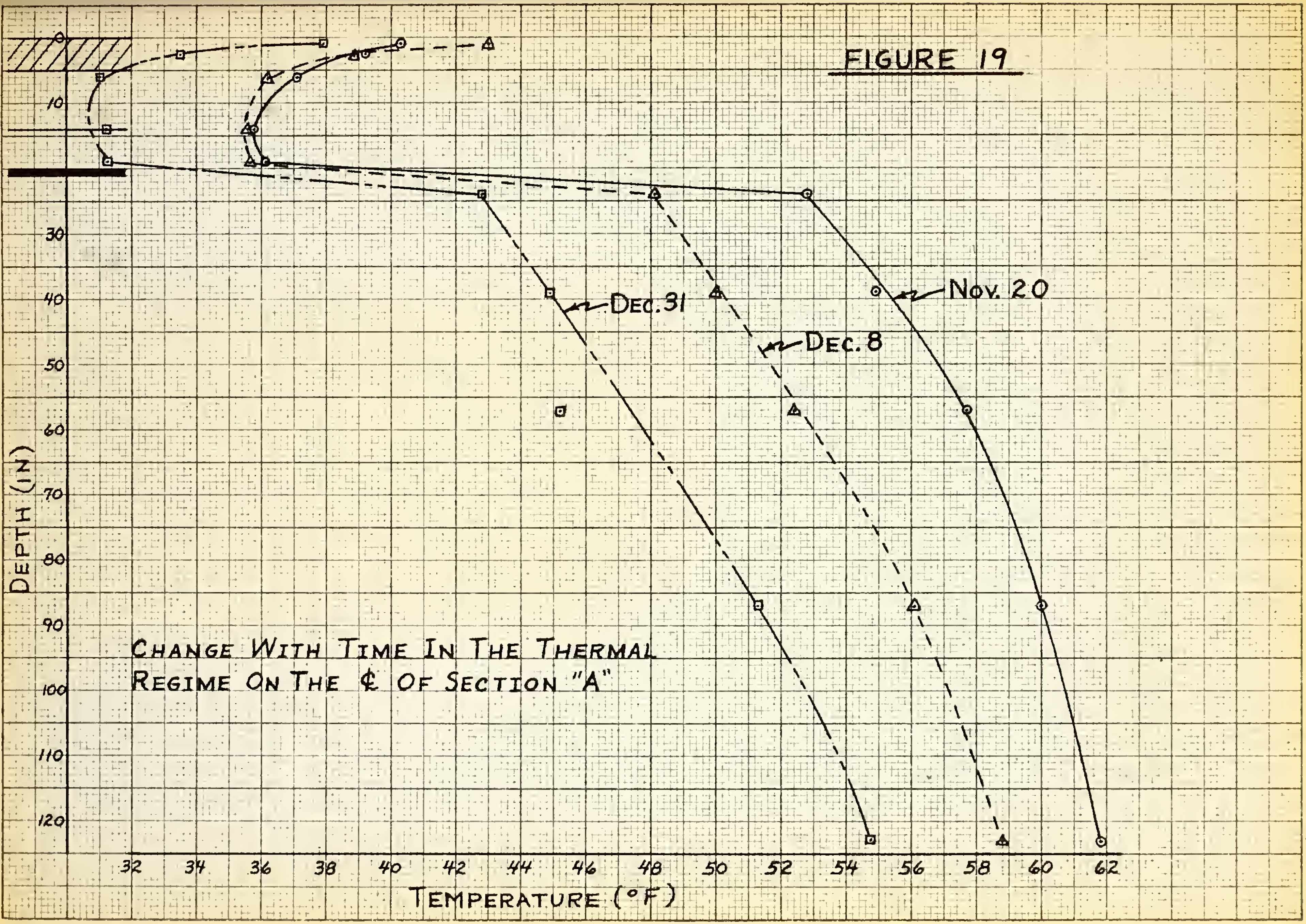
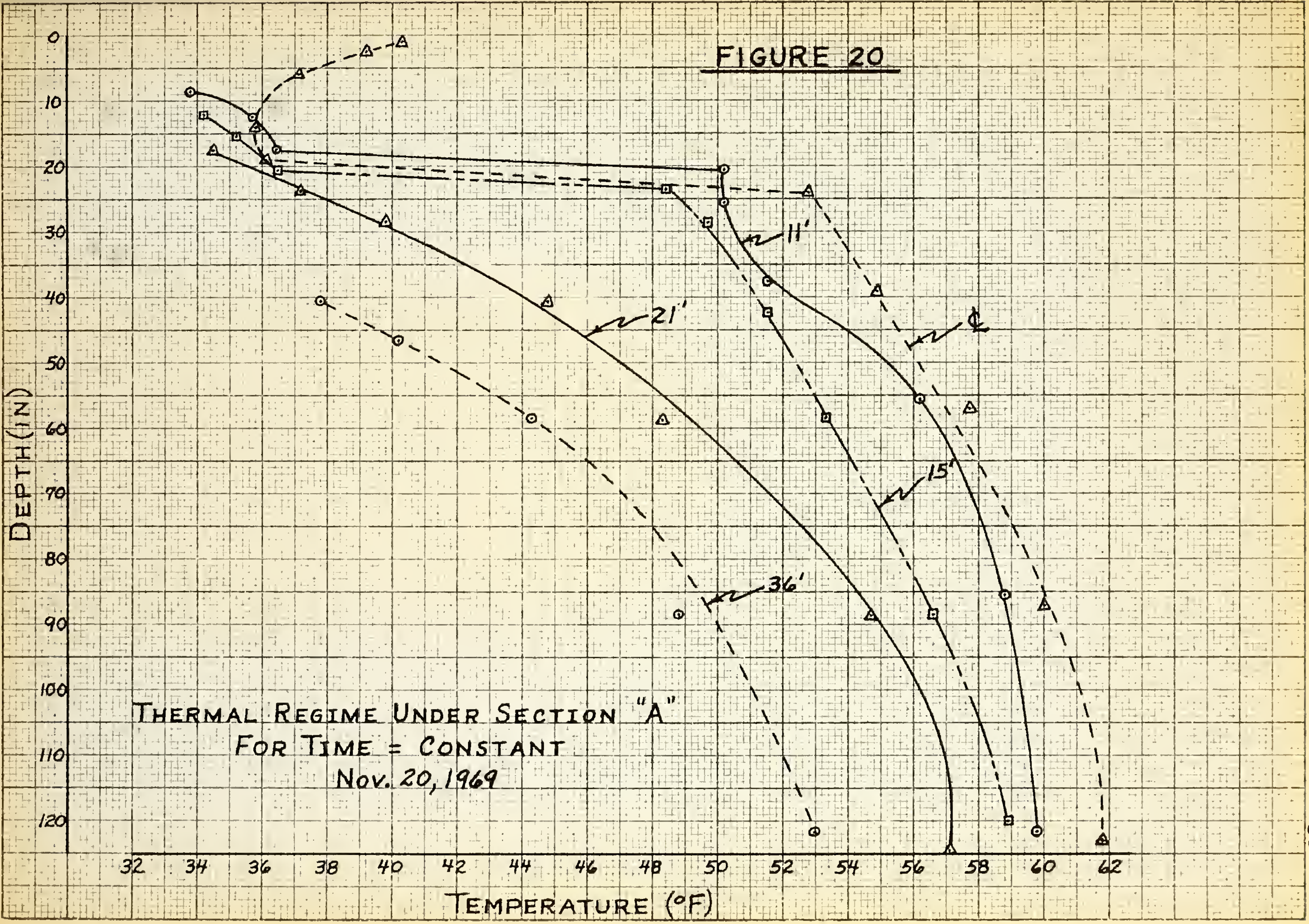


FIGURE 19

CHANGE WITH TIME IN THE THERMAL
REGIME ON THE ℄ OF SECTION "A"

FIGURE 20



THERMAL REGIME UNDER SECTION "A"
FOR TIME = CONSTANT
NOV. 20, 1969

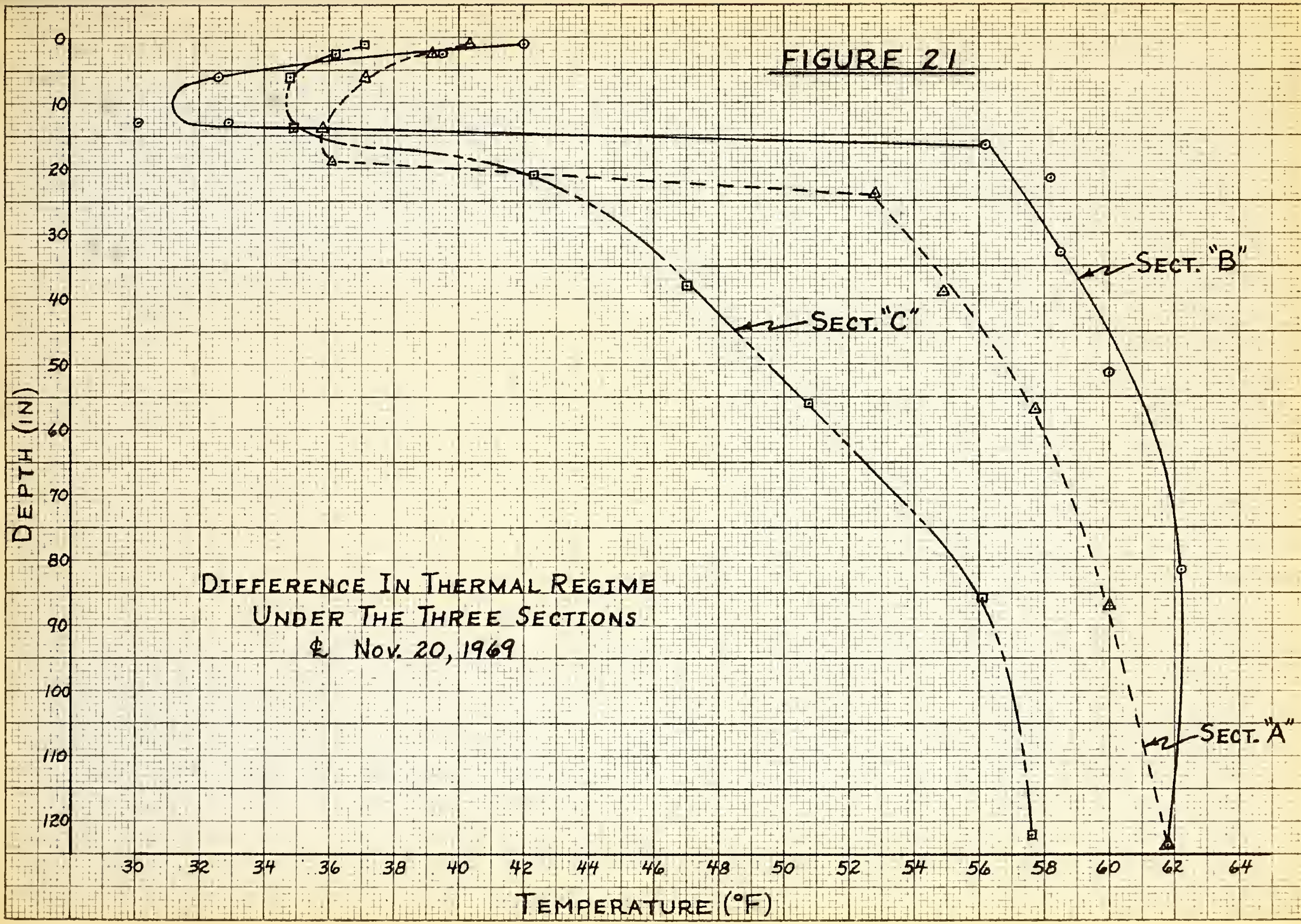

Sect. "B"
Sect. "C"
Sect. "A"
Difference In Thermal Regime
Under The Three Sections
℄ Nov. 20, 1969
Depth (in)
0
10
20
30
40
50
60
70
80
90
100
110
120
Temperature (°F)
30
32
34
36
38
40
42
44
46
48
50
52
54
56
58
60
62
64

FIGURE 21

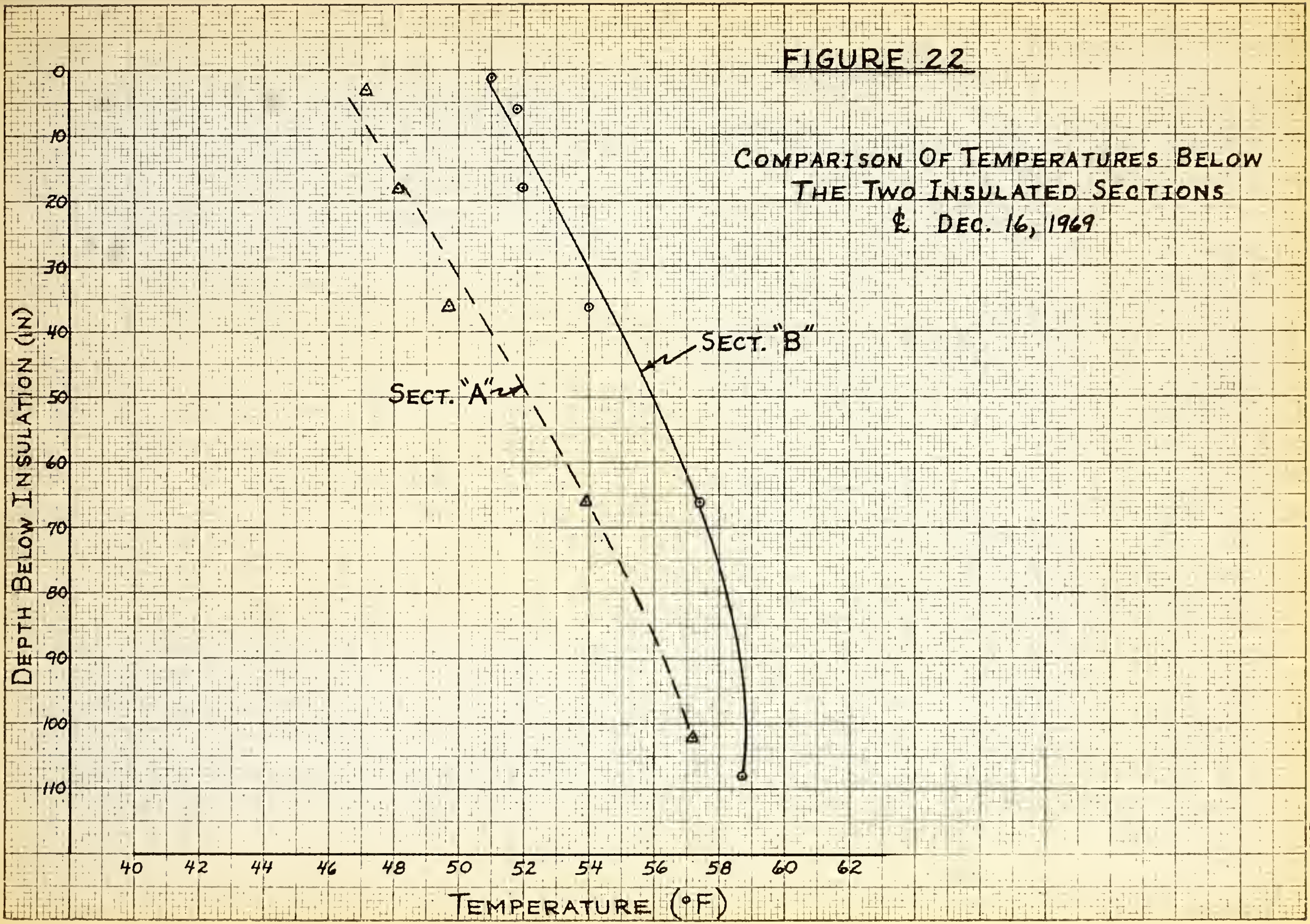
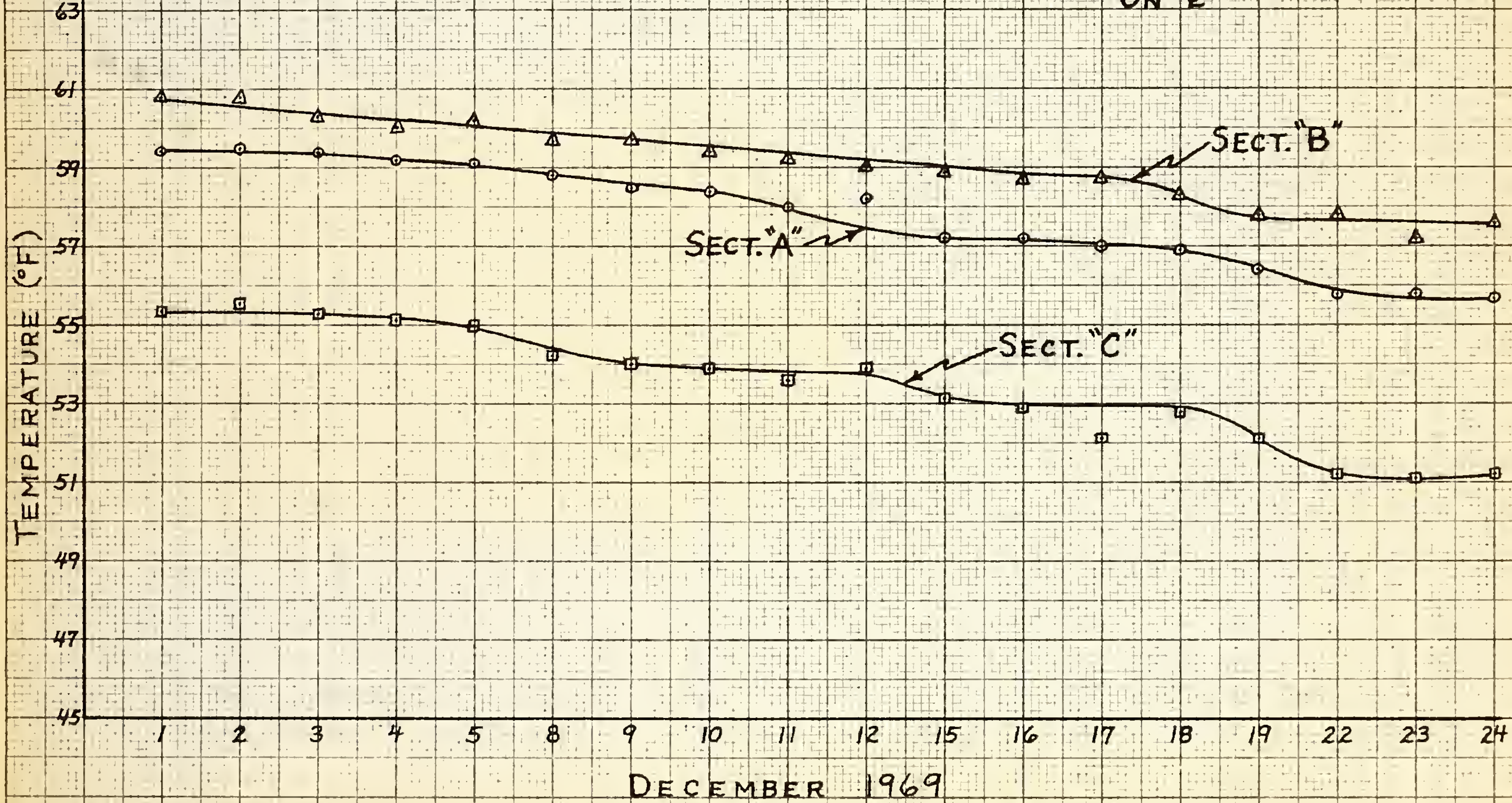


FIGURE 22
COMPARISON OF TEMPERATURES BELOW
THE TWO INSULATED SECTIONS
℄ DEC. 16, 1969
SECT. "B"
SECT. "A"
DEPTH BELOW INSULATION (IN)
0
10
20
30
40
50
60
70
80
90
100
110
40
42
44
46
48
50
52
54
56
58
60
62
TEMPERATURE (°F)

FIGURE 23

CHANGE IN TEMPERATURE OF THE DEEPEST THERMISTORS WITH TIME ON ℄

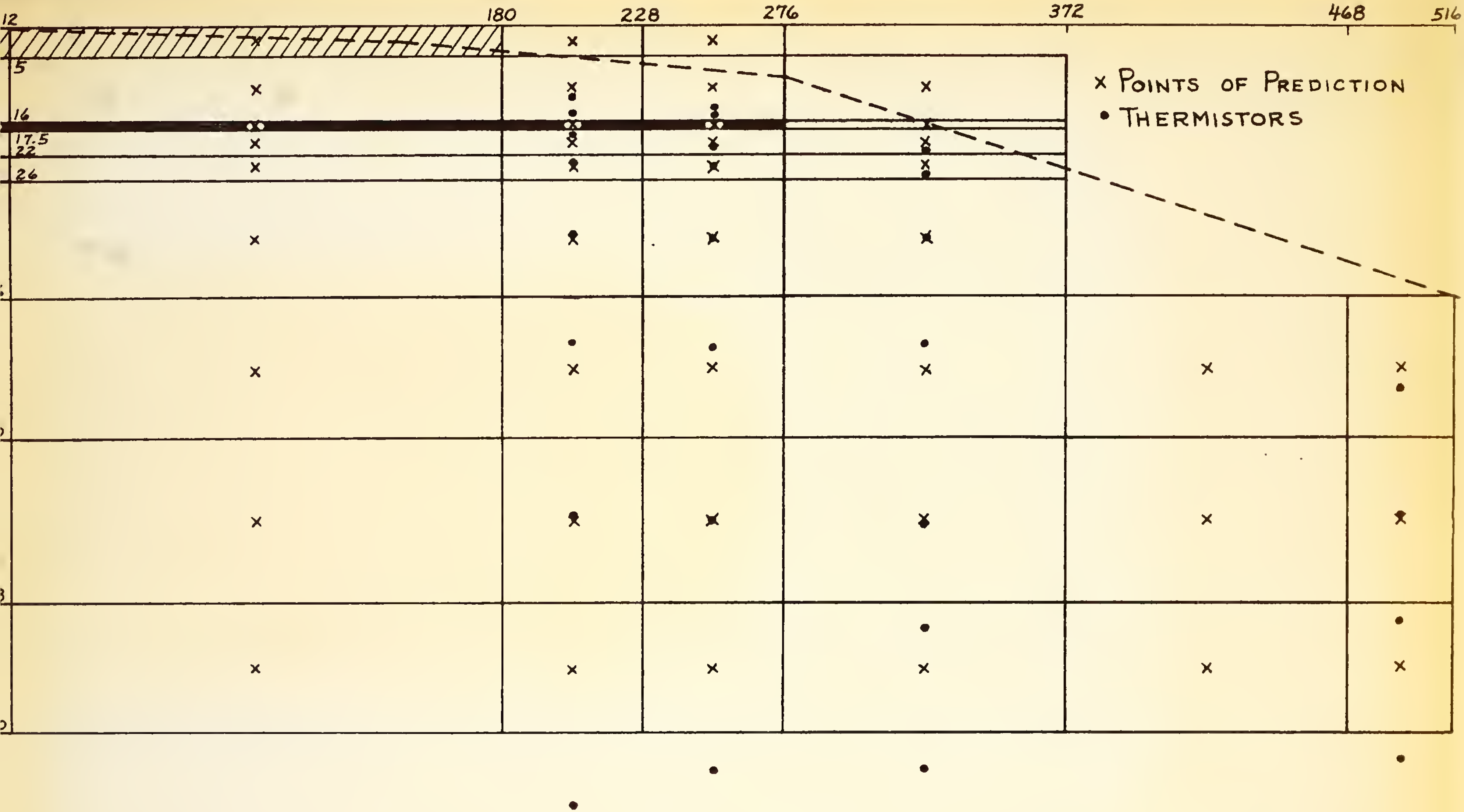


As a first step in the preparation of the program it is necessary to divide the three sections into elements or cells. The temperature will be predicted in the center of each cell and therefore the sections were divided to make the points of prediction as close as practicable to the real thermistor locations. Figures 24 through 26 show the three sections and their cells. Each section is divided into rectangles (cells) of various sizes by horizontal and vertical lines. The space between two horizontal lines is called a row, while the space between two vertical lines is called a column. The origin for both row and column numbering is the pavement surface at the centerline if the road. The various types of cells are illustrated in Figure 27. The types and dimensions of the cells are given in Table 2.

The input data required for the 2-D heat flow model consists of daily mean air temperatures, boundary temperatures in the soil, cell types, equations for the amount of soil water frozen with temperature, and the unit weight, water content, volumetric heat, and thermal conductivity of the various materials.

The input temperature data required will be obtained from actual temperature measurements at the site. The first few weeks accumulation of daily mean air temperatures is given in Table 3. Assumed equations for the amount of soil water frozen with temperature are given in Table 4. As a first approximation of the unit weight, water content, volumetric heat, and thermal conductivity of the materials, the values used by Stulgis [3] will be applied. These are given in Table 5.

No predictions have been carried out to date, significant discrepancies between measurements and predictions may motivate several research



Note: Given Dimensions Are In Inches

Figure 24. Cells Showing Points of Predictions & Thermistors - Section "B"

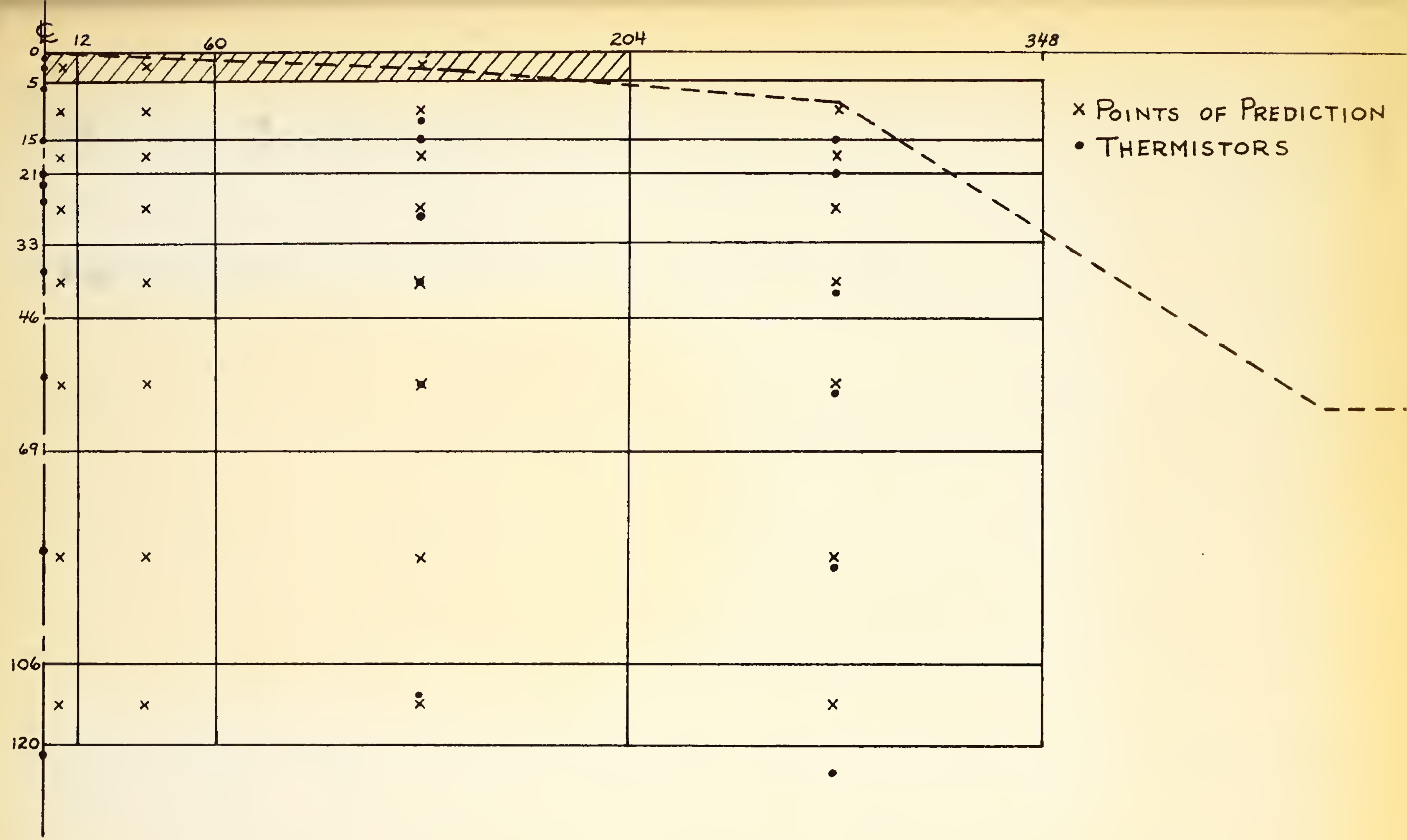


Figure 25. Cells Showing Points of Predictions & Thermistors – Section "C"

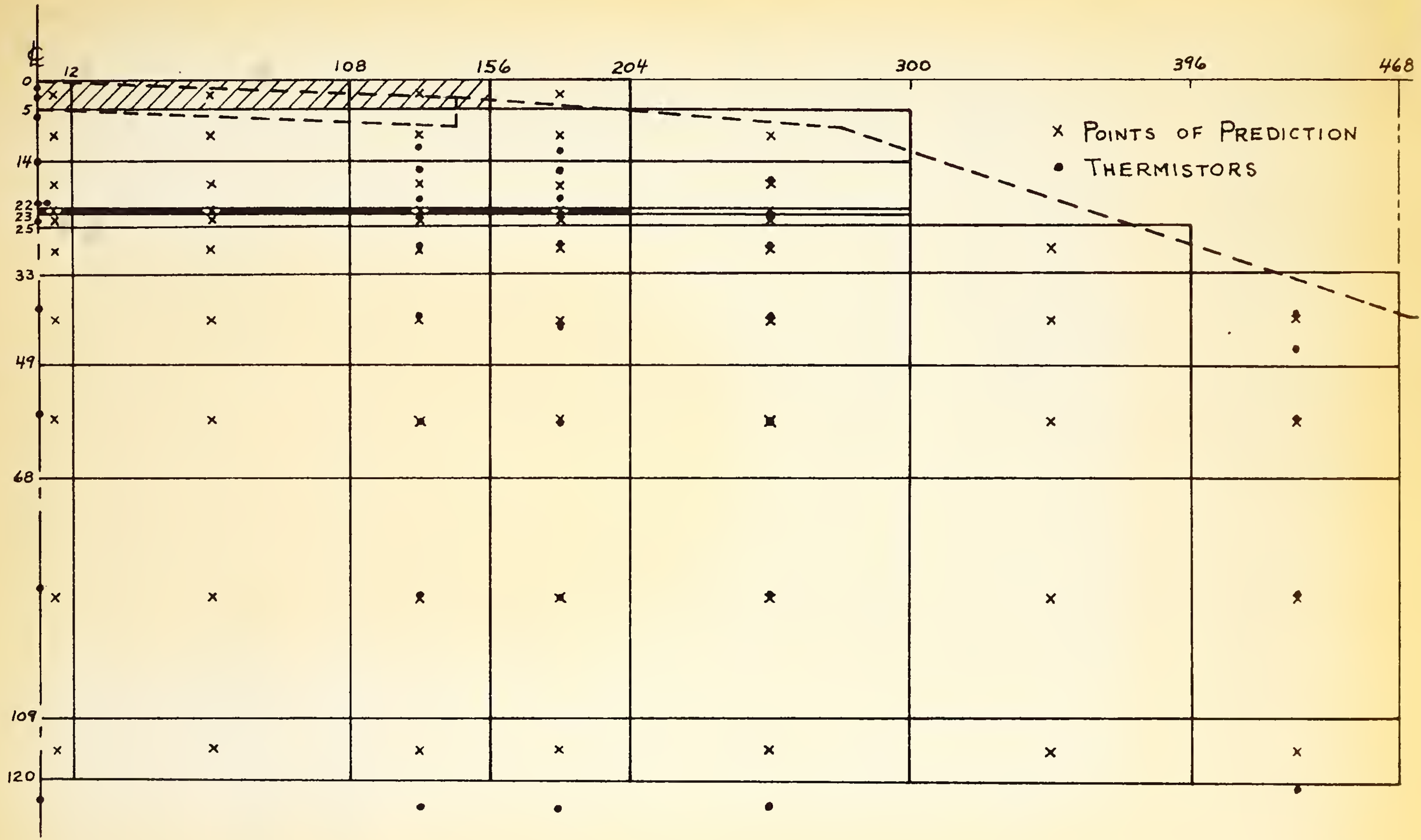
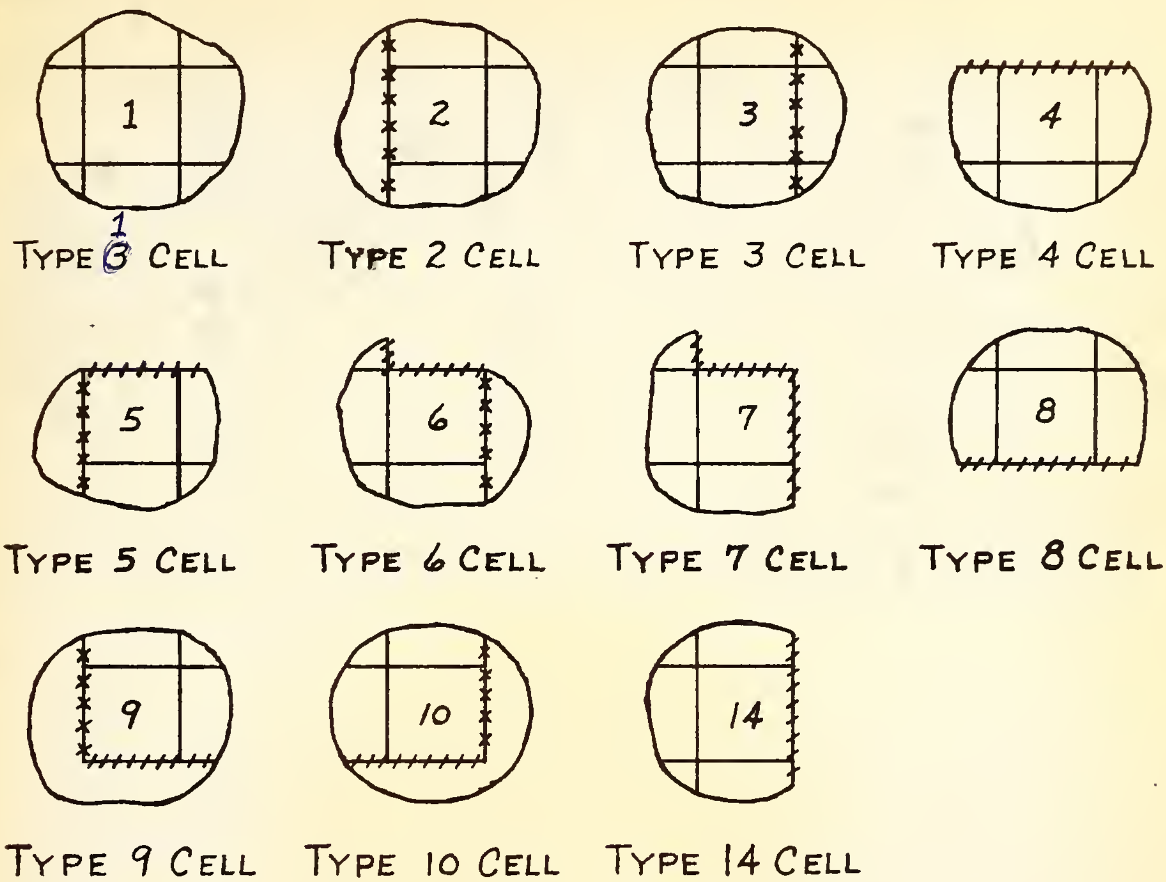
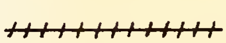


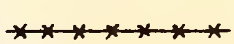
Figure 26. Cells Showing Points of Predictions & Thermistors - Section "A"

TYPES OF CELLS

TYPE OF CELL REFERS TO THE BOUNDARY CONDITIONS OF THE CELL AS SHOWN BELOW:




SECTION BOUNDARIES


SECTION BOUNDARIES AND ASSUMED THERMAL BOUNDARIES

CELL TYPES 11, 12, AND 13 ARE NOT REQUIRED FOR THIS PARTICULAR PROBLEM

FIGURE 27

TABLE 2

TYPES AND DIMENSIONS OF CELLS

SECTION "A": 58 CELLS

Row	Column / Thickness(in) \ Width(in)	1 12"	2 96"	3 48"	4 48"	5 96"	6 96"	7 72"
1	5"	5	4	4	7	-	-	-
2	9"	2	1	1	1	7	-	-
3	8"	2	1	1	1	14	-	-
4	1"	2	1	1	1	14	-	-
5	2"	2	1	1	1	14	-	-
6	8"	2	1	1	1	1	7	-
7	16"	2	1	1	1	1	1	6
8	19"	2	1	1	1	1	1	3
9	41"	2	1	1	1	1	1	3
10	11"	9	8	8	8	8	8	10

SECTION "B": 50 CELLS

Row	Column / Thickness \ Width	1 12"	2 168"	3 48"	4 48"	5 96"	6 96"	7 48"
1	5"	5	4	4	7	-	-	-
2	11"	2	1	1	1	7	-	-
3	1 1/2	2	1	1	1	14	-	-
4	4 1/2	2	1	1	1	14	-	-
5	4"	2	1	1	1	14	-	-
6	20"	2	1	1	1	14	-	-
7	24"	2	1	1	1	1	7	6
8	28"	2	1	1	1	1	1	3
9	22"	9	8	8	8	8	8	10

TABLE 2 (CONT'D)

TYPES AND DIMENSIONS OF CELLS

SECTION "C": 30 CELLS

Row	Column	1	2	3	4
	Thickness \ Width(in)	12"	48"	144"	144"
1	5"	5	4	7	-
2	10"	1	1	1	6
3	6"	1	1	1	3
4	12"	1	1	1	3
5	13"	1	1	1	3
6	23"	1	1	1	3
7	37"	1	1	1	3
8	14"	9	8	8	10

TABLE 3

MEAN AIR TEMPERATURES

DATE	T(°F)
Nov. 26	39.3
27	33.3
28	27.3
29	32.5
30	34.5
Dec. 1	32.0
2	35.4
3	34.0
4	27.5
5	28.5
6	34.5
7	38.0
8	33.5
9	37.0
10	35.3
11	34.0
12	26.0
13	35.4
14	32.8
15	34.0
16	30.0
17	32.5
18	33.6
19	26.3
20	23.5
21	26.8

DATE	T(°F)
Dec. 22	29.8
23	17.5
24	12.0
25	27.3
26	24.8
27	22.2
28	28.5
29	32.0
30	31.5
31	29.0
Jan. 1	24.0
2	22.7
3	12.0
4	17.5

TABLE 4

ICE FORMATION RELATIONS IN EXPONENTIAL FORM

SECTION "A"

CELLS	
(1,1),(1,2),(1,3)	DRY CELLS
(1,4),(2,1),(2,2),(2,3) (2,4),(2,5),(3,1), (3,2),(3,3),(3,4),(3,5)	PERCENT WC[1] FROZEN = 100.00-EXP(.167*T(I,J,K)+-.733)
(4,1),(4,2),(4,3),(4,4)	DRY CELLS
(4,5), & ALL OTHERS	PERCENT WC FROZEN = 62.00-EXP(.253*T(I,J,K)+-3.977)

SECTION "B"

(1,1),(1,2)	DRY CELLS
(1,3),(1,4),(2,1),(2,2), (2,3),(2,4),(2,5)	PERCENT WC FROZEN = 100.00-EXP(.167*T(I,J,K)+-.733)
(3,1),(3,2),(3,3),(3,4)	DRY CELLS
(3,5), & ALL OTHERS	PERCENT WC FROZEN = 62.00-EXP(.253*T(I,J,K)+-3.977)

SECTION "C"

(1,1),(1,2),(1,3)	DRY CELLS
(2,1),(2,2),(2,3),(2,4), (3,1),(3,2),(3,3),(3,4)	PERCENT WC FROZEN = 100.00-EXP(.167*T(I,J,K)+-.733)
ALL OTHERS	PERCENT WC FROZEN = 62.00-EXP(.253*T(I,J,K)+-3.977)

---

1. PERCENT WC = water content in percent. See Ho [1] for additional explanations.

TABLE 5

PROPERTIES OF THE CELLS

SECTION "A"

cells (row, column)	unit weight(pcf)	water content(%)	Volumetric heat($btu/ft^3/^oF$)	Conductivity ($btu/ft/hr/^oF$
(1,1),(1,2), (1,3)	143	0	$c_o = c_1\theta + 30.5$	$k = c_3\theta + 0.84$
(1,4),(2,1), (2,2),(2,3), (2,4),(2,5)	145	4	$c_o = c_1\theta + 25.4$	$k = c_3\theta + 1.9$
(3,1),(3,2), (3,3),(3,4), (3,5)	120	4.8	$c_o = c_1\theta + 25.4$	$k = c_3\theta + 1.9$
(4,1),(4,2), (4,3),(4,4)	1.8	0	$c_o = c_1\theta + 0.5$	$k = c_3\theta + 0.022$
(4,5) & all others	108	17	$c_o = c_1\theta + 21.6$	$k = c_3\theta + 1.17$

SECTION "B"

cells	unit wgt.	water content	Volumetric heat	Conductivity
(1,1),(1,2)	143	0	$c_o = c_1\theta + 30.5$	$k = c_3\theta + 0.84$
(1,3),(1,4), (2,1),(2,2), (2,3),(2,4), (2,5)	145	4	$c_o = c_1\theta + 25.4$	$k = c_3\theta + 1.9$
(3,1),(3,2), (3,3),(3,4)	1.8	0	$c_o = c_1\theta + 0.5$	$k = c_3\theta + 0.022$
(3,5) & all others	108	17	$c_o = c_1\theta + 21.6$	$k = c_3\theta + 1.17$

TABLE 5 (CONT'D)

PROPERTIES OF THE CELLS

SECTION "C"

cells	unit weight(pcf)	water content(%)	Volumetric heat(btu/ft^3/^{o}F	Conductivity (btu/ft/hr/^{o}F
(1,1),(1,2), (1,3)	143	0	$c_o = c_1\theta + 30.5$	$k = c_3\theta + 0.84$
(2,1),(2,2), (2,3),(2,4)	145	4	$c_o = c_1\theta + 25.4$	$k = c_3\theta + 1.9$
(3,1),(3,2), (3,3),(3,4)	120	4.8	$c_o = c_1\theta + 25.4$	$k = c_3\theta + 1.9$
all rest	108	17	$c_o = c_1\theta + 21.6$	$k = c_3\theta + 1.17$

Note:

θ = Temperature

c_1 and c_3 = constants = 0 for these materials

(Cell (2,3) refers to the cell in row 2 and column 3)

activities. One of the more obvious of those would be the refinement of physical and thermal property input for the prediction model. The Research and Training Center has site information and soil samples available for this purpose.

SUMMARY

The construction of the Indiana insulated test road near Rossville has been successfully completed. The instrumentation is in place and all but a few of the thermistors appear to be operating in a satisfactory manner.

Routine data collection has begun, and the preliminaries for prediction of the thermal regime have been completed. There appears to be no deterrent to implementation of the total performance study as previously planned.

BIBLIOGRAPHY

1. Ho, Da-Min, "Prediction of Frost Penetration Into a Soil-Water System", Ph. D. Thesis, Purdue University, August, 1969.
2. Lovell, C. W. Jr. and R. P. Stulgis, "Planning for a Thermally Insulated Test Road", Joint Highway Research Project Report No. 28, October 1968.
3. Stulgis, R. P., "Insulated Test Road ... State Road 26", Joint Highway Research Project Report No. 12, July 1968.
4. "Indiana Highway Gets Polystyrene Frost Barrier", Construction Digest, September 25, 1969.